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Observatoire de Paris

61, Avenue de l'Observatoire
Paris XIV°

FINAL REPORT

Contract N° DA-91-591-EUC-1752

THE STABILITY AND Q-FACTOR OF QUARTZ-CRYSTALS EXCITED BY THE PARALLEL FIELD TECHNIQUE

Report Covers Period :

1 MAY 1961 to 30 APRIL 1963

The research reported in this document has been made possible throught the support and sponsorship of the U.S. Department of the Army, throught its European Research Office. This Report, not necessarly in final form, is intended only the internal management use of the Contractor and U.S. Department of Army.

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Final Report

The Stability and Q-Factor of Quartz-Crystals

Excited by the Parallel Field Technique

PURPOSE :

The basic purpose of the contract is the research on the stability and Q factor of quartz crystal resonators excited by the parallel field technique.

The project has involved three separate phases:the first is the investigation of parallel field excited resonators, the second is the study of the normal field excitation using the annular electrodes;and the third concerns the development of the composed field excitation technique.

The purpose of this final report is to review the accomplished work and to summarize the results and the conclusions.

ABSTRACT.

This project has been concerned with the development of parallel field excited crystals with the purpose of obtaining quartz crystal resonators having high Q and low aging.

Phase I was devoted to the study of the electrical parameters of parallel field excited crystals and their variation as a function of the plating pattern. Quality factors of 6×10^6 were obtained with a gap of about 1mm.

Phase II concerned the investigation of the rise of Q. Parallel field excited crystals with wide gap showed Q's up to 10×10^6.This led to the conclusion that the main factor limiting Q is the damping due to the metal film deposited on the surface of the crystals,especially in the center.

Series of measurements was carried out with the normal field excitation using annular electrodes, which is the reversed method as compared to conventional plating. An increase of the central unplated area is followed by an increase of the Q-value, which confirmed the above conclusion.

Phase III involved the elimination of the weak points of both described methods, i.e. too high inductance in case of the parallel field and too high capacity. in case of the normal field excitation using annular electrodes. The starting point of this development was the study of the discrepancy in Q values of parallel field excited crystals with a narrow gap. This led to the composed field excitation, which is the combination of the parallel and of the normal fields. The components of these fields give a resultant along the Y axis which increases the excitation and enables a further reduction of the plating.

CONFERENCES:

1. The undersigned visited USASRDL 23 and 24 April an 2 May 1962.
   The question of different methods of excitation was discussed with Dr. Gerber, Dr. Guttwein, Dr. Bechmann, Dr. Hafner, Mr. Ballato and Mr. Bernstein. The programm for the future work at the Paris Observatory has been set.
2. Dr. Guttwein of U.S. Army Electronics Research and Development Laboratory and Lt. Colonel Harry F. Sieber of European Research Office visited the Paris Observatory on 28 and 29 November 1962. The purpose of the visit was to review the progress of the work, to discuss several technical points which may improve the performances of the crystals, to choose the samples of three types of crystals excited by the parallel, normal annular and composed field in view of aging test and to set the programm for the second contract regarding the development of the composed field technique and its application for crystals of different sizes and frequency on the fundamental and overtone modes.
3. The undersigned visited the European Research Office, Frankfurt, Germany and discussed with Lt. Colonel H.F. Sieber on 21 December the proposal for the second development contract. This proposal was submitted on 2 January 1963.

REFERENCES:

1. Bechmann R. "Parallel Field Excitation of Thickness modes of Quartz Plates" Proceedings of the 14th Annual Symposium on Frequency Control 1960.
2. Ianouchevsky W. "Quartz Etalons Lenticulaires Excités par le Champ Parallèle",Annales Françaises de Chronométrie, 31ème année, 2ème série, tome XV 1961.
3. Warner A.W. and Stockbridge C.D. "The Measurement of Mass Using Quartz Crystal Resonators" Symposium on Vacuum Microbalance Technique, 30 October 1962.
4. Paris Observatory patent application P.V. 799 799 of 9 July 1959. French patent delivered 11 July 1960 under N° 1.238.898.
5. Paris Observatory patent application P.V. 832 249 of 6 July 1960. French patent delivered 10 July 1961 under N° 1.269,750.
6. Paris Observatory patent application P.V. 925 806 of 23 February 1963.

DISCUSSION :

PHASE I

Pnase 1 was the initial investigation of the excitation of crystals with the parallel field.

I Mc. bi-convex crystals of 26.8mm. diameter and 110mm radius of curvature were used for the study of the electrical parameters. These crystals were vacuum plated with a semi-transparent layer of chromium followed by the evaporation of silver and adjusted to the nominal frequency by nickel electroplating.

First measurements of crystals with a gap of lmm. along the X axis showed a marked increase of the Q-factor, as compared with conventionally plated crystals.

The minimum motional inductance of parallel field excited crystals is about 40 to 50 times higher than the inductance of the same crystal excited by the perpendicular field using central electrodes.

L and R rise rapidly when the gap is widened. This is shown by Fig I.p.15. The examination of the plotted L and R curves as a function of the gap brought to the important conclusion that the rise of the inductance is followed by a steady increase of the L/R ratio. Q's up to 10×10^6 were obtained with very large gaps.

The similar increase of L/R ratio may be obtained by altering the plating pattern according to Fig 2, p.15 Instead of widening the gap (unplated surface limited by parallel lines), the plating mask provides a circular unplated surface in the center. The increase of the diameter of this circular surface is followed by the increase of Q. This shows the importance of the damping produced by the metal film on the most active part of the crystal surface.

The parallel field excited crystals are exhibit excellent frequency/temperature and very good resistance/temperature curves.

The turning point temperature is dependent on the width of the gap. With the increase of the gap, ZTC moves towards the lower temperature region. For example a I Mc. crystal cut to 34°56' and plated with a gap of 0.8mm.has its ZTC at 50°C. The same crystal replated with a 4mm. gap exhibits the turning point at 18°C.

Typical data of a I Mc. crystal soldered at two points to the supporting pins of the holder are shown in the table of Fig. 3, p.16

Measuring the inductance of crystals plated with a gap of 0.8mm, it was found that its values vary in widly from 58 to 120 H. Close investigation of this phenomena showed that the reason for this discrepancy is the following :

As flexible metal ribbons are used to mask the gap, it is very difficult to assure the exact superposition of these ribbons in the plating mask. The shift of one ribbon in respect to the other introduces a normal field component. If the addition of this component to the parallel field pushes the resultant field toward Y axes, low values of L are obtained. In opposite case the L value rises.

The weak point of the parallel field excitation resides in too high values of the inductance, specially in the low frequency range. This inconvenience diminishes when the parallel field is applied to the crystels of higher frequencies. The lack of equipment and time did not permit the exploration of the upper range of frequencies in which the application of the parallel field presents a real interest.

PHASE II

It was pointed out above that crystals having parallel field excitation, large unplated central surface, and small gaps close to the edge exhibite high Q's. This observation led to the consideration of normal field excitation leaving the central part of the crystal free from metal film.

It is well known that conventionally plated crystals have very low inductance and if Q is high, the resistance is very small. Both values can be raised by the reduction of plated surface, but in this case the L/R ratio drops rapidly.

Annular electrodes were used to excite the crystal by the normal field, which is a reversed pattern as compared with the conventional plating. Fig 4, p.17 shows this type of electrodes.

A plot of L_s values was obtained corresponding to different diameters of the inner circle; the curve is shown by Fig. 5, p.17. This curve is similar to the inductance curve corresponding to the parallel field excitation. The rise of the inductance is followed also by the steady increase of the L/R ratio.

The described method gives the possibility of varying the value of L within very wide limits. For example a I Mc crystal plated with a I mm^2 inner circle exhibits the inductance of mm about 20 H. which may be considered as the lowest practical value. The unplated surface represents about 18% of the total surface of the crystal. The same crystal excited by the parallel field, and having a narrow gap of 0.8mm. to keep the inductance value as low as possible, has an unplated surface of only 3.7% of the total surface.

As regards the quality factor, the normal field using annular electrodes gives the same possibilities as the parallel field.

The typical data of a 1 Mc. crystal are given on Fig. 6, p. 18

The weak point of normal field excitation with annular electrodes are of two kinds: first, as the plating extends close to the edge the static capacity is high, of about 25 to 30 pF; second, the excitation of the unwanted modes is stronger as compared with the parallel field excitation.

The results obtained with two described technique of excitation showed the way for further development and gave a clear indication that the central area of the crystal must be kept free from plating to assure high Q's.

PHASE III

Phase III of the contract has been concerned with the development of a method of excitation which eliminates the weak points of parallel and normal field excitations.

The goal to approach was: first to keep the inductance value under 50 H, second, to obtain a L/R ratio higher than unity for I Mc. crystal, and third, to have a static capacity of about 7pF.

The study of the discrepancy in L values with parallel field excitation gave the first indication that the introduction of the normal field component may solve the problem.

To clearly indicate the mechanism of the variation of L as function of the direction of the field a series of measurements was done on the unplated crystals altering the parallel and normal field components

A special fixture shown on fig 7,p. 19 was designed to permit the displacement of the electrodes parallel to themselves and to permit variation of the gap between the electrodes.

Square electrodes measuring 30×30mm. were assembled according to Fig.8, p. 20 a shows the set of the electrodes for the parallel field excitation. For the normal field excitation two electrodes were removed as shown in Fig. 8b. The lateral displacement of the electrodes made it possible to vary the parallel and normal field components.

The curves of Fig. 9, p. 21 show the variation of L,R and Q as function of the distance between the centers of the electrodes for a gap of 10 mm. Fig 10, p. 22 gives the same curves for the gap of 8 mm. The absolute values in both cases are different, but the shape of the curves is similar. The Q-curves have the marked maxima when the field is directed along Y axis. Taking into account the refraction of the field in quartz, the line joining the centers of the electrodes makes an angle greater than Θ.

The diagram of Fig 11, p. 23 shows the parallel and normal field components designated by Pf and Nf. The resultant of these components is directed along Y axis if Pf/Nf = tang. Θ.

This is achieved by the plating patterns. The simplies pattern is derived from the arrangement of electrodes for the parallel field excitation in which nearly half of the metal film is removed from each side and the remaining electrodes overlap a narrow strip along the XX axis. Fig. 12, p. 24 shows the plating pattern described above.

By altering the overlap of opposed platings, it is possible to vary the inductance and the resistance. This is difficult, as on one hand small variations in the overlaping surfaces are followed by important changes in L and R, and on the other hand, it is also difficult to adjust the parallel and normal field components to optimize the Q-factor; (deviation of the resultant from the Y direction).

Fig. 13, p. 24 gives the data of a I Mc crystal excited by the composed field using the plating pattern accordingly to Fig. 12.

As it is essential to keep the center of the crystal free of metal, the plating pattern was designed accordingly to Fig. 14, p. 24. Two semi-annular electrodes on the opposed faces of the crystal and opposed end of ZZ' axis produce the parallel field component, and two extensions of the plating from the both sides of the unplated inner circle gives the normal field component. L and R can be varied by altering the diameter of the unplated central surface, followed by the readjustment of the overlaping surfaces. The data of crystals excited with the composed field are given in Fig. 15. p. 15.

At present statistical data one aging are failling. The preliminary aging tests have shown that the aging of composed field excited crystals is less that those excited by the parallel field with nearly the same inductance.

In appendix are given the results of the frequency measurements of N° 242 crystal, excited by the composed field and driven by a transistor oscillator at CNET Frequency Laboratory and also the figures showing the initial aging of N° 96 crystal excited by the parallel field.

OVERALL CONCLUSIONS:

The comparison of three described methods of excitation shows that the composed field technique exhibits the advantages of the parallel field excitation and eliminates very high inductance which is the weak point of the letter.

Crystals excited by the composed field have a high Quality Factor and their inductance can be kept within the limits enabling an easy impedance match.

As the plated surface is reduced to the minimum, it is believed that the aging of such excited crystals can by substantially reduced.

RECOMMENDATIONS :

It is recommended that consideration be given to the extention of the composed field technique to other frequencies and sizes of crystals.

If the inductance of crystals is mainly dependent on the geometry of the electrodes, the resistance is subject to variation and depends on the suspension. Therefore it is recommended that consideration be given to the extensive development of a few specific crystals from technical and technological points of view.

It is also recommended that consideration be given to the difficult, but very interesting problem of the excitation of non plated crystals by the composed field.

IDENTIFICATION OF PERSONNEL:

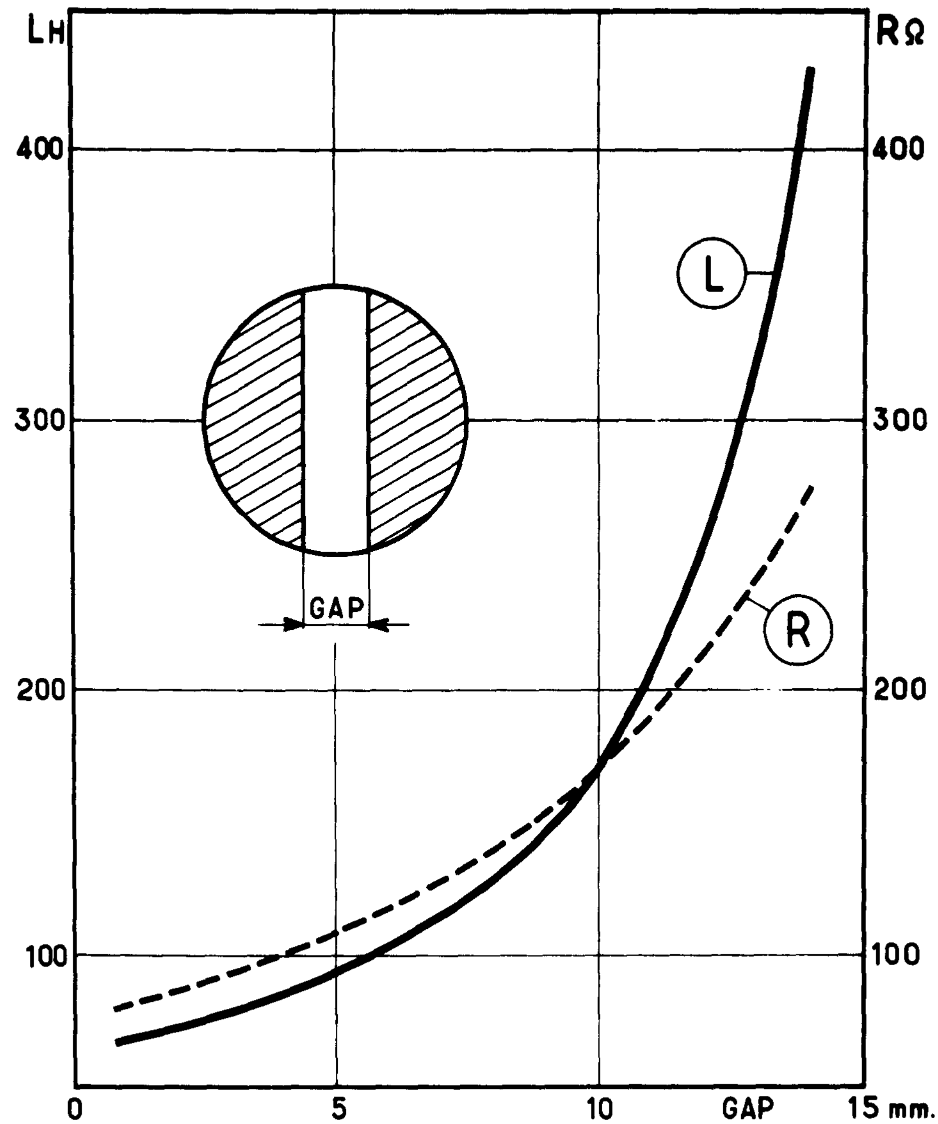
W. Ianouchevsky	-Graduated Naval Academy (Russia) Industry: Ets. Belin, Rueil Malmaison, S & O; in charge of the development of the phototelegraphy (1927 - 1944) Laboratoires Radioélectriques, Paris. Head of Crystal Department 1944 - 1950 Quartz et Electronique, Asnières Seine, Director 1951 - 1959
R. Florent	Optician. 1929 - 1945 General optics at CRPI, Puteaux Seine Since 1945 working in the field of quartz-crystals; 1945 - 1953 Radio A.I.R., Asnières, Seine. 1953 - 1958 Quartz et Electronique, Asnières, Seine.
L. Delille	Technician. Received electronic training in the French Navy. After serving in the Navy, worked at Paris Observatory in the electronic laboratory of the Time Department.

SUMMARY OF MAN HOURS:

W. Ianouchevsky	3360
R. Florent	4540
L. Delille	4500

The principal investigator under the contract

W. Ianouchevsky



// FIELD L AND R AS FUNCTION OF THE GAP. Fig. 1

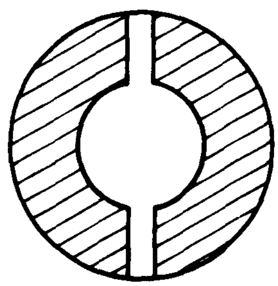
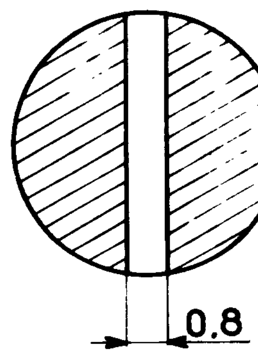


Fig. 2

	C_1 10^{-4} pF	L H	R_A Ω	R_V Ω	R_A/R_V	C_0 pF	Q 10^6
CRYSTAL # 97	3.73	66.9	670	77	8.7	4.8	5.4
CRYSTAL # 98	3.54	71.5	668	70	9.5	4.8	6.4
CRYSTAL # 99	3.11	81.3	725	79	9.2	4.8	6.4



DATA FOR IMc CRYSTAL WITH
PARALLEL FIELD EXCITATION

Fig. 3

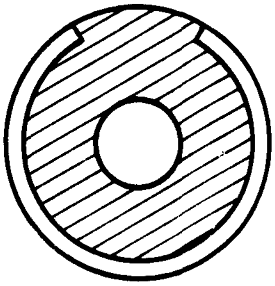
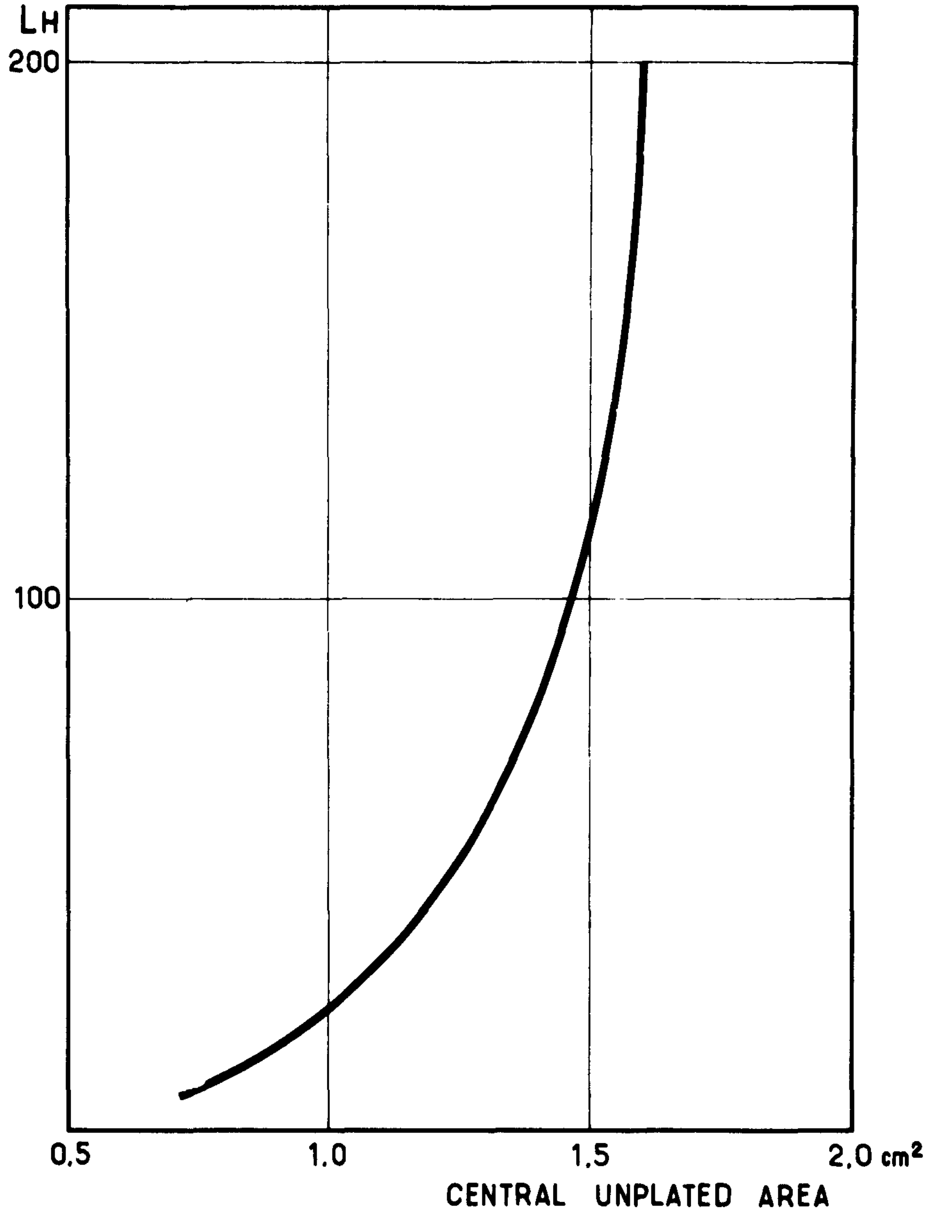
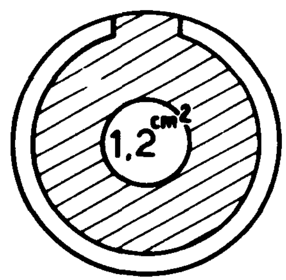


Fig. 4



⊥ FIELD L AS FUNCTION OF CENTRAL UNPLATED SURFACE. Fig. 5

	C_1 10^{-4} pF	L H	R_A Ω	R_V Ω	R_A/R_V	C_0 pF	Q 10^6
CRYSTAL # 223	7,96	31,8	355	27	13,1	30	7,4
CRYSTAL # 226	7,69	32,9	327	33	9,9	30	6,3
CRYSTAL # 232	7,84	32,3	328	26	12,6	30	7,8



DATA FOR IMc CRYSTAL WITH NORMAL FIELD EXCITATION, ANNULAR ELECTRODES, CENTRAL UNPLATED SURFACE 1,2 cm^2 .

Fig. 6

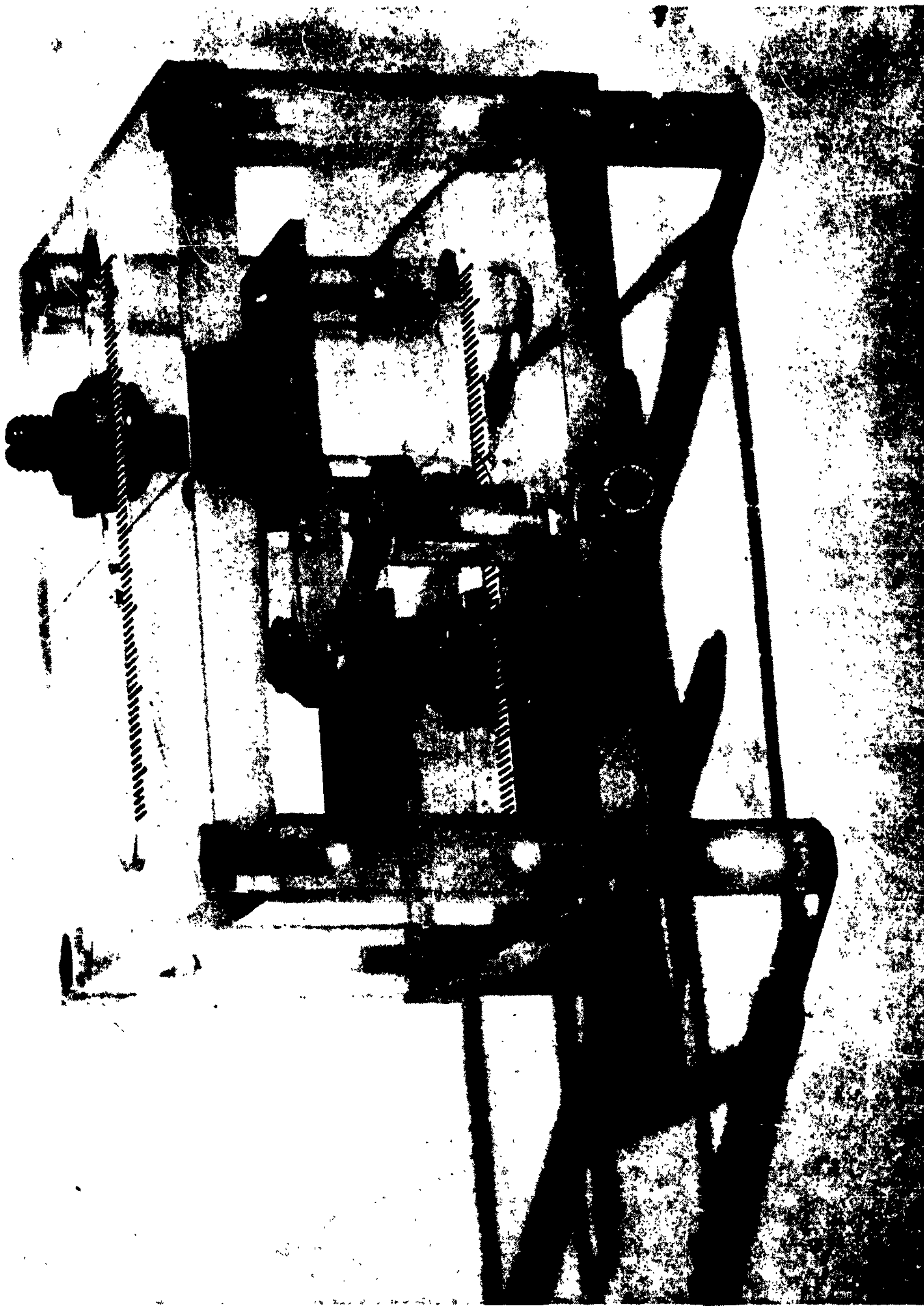
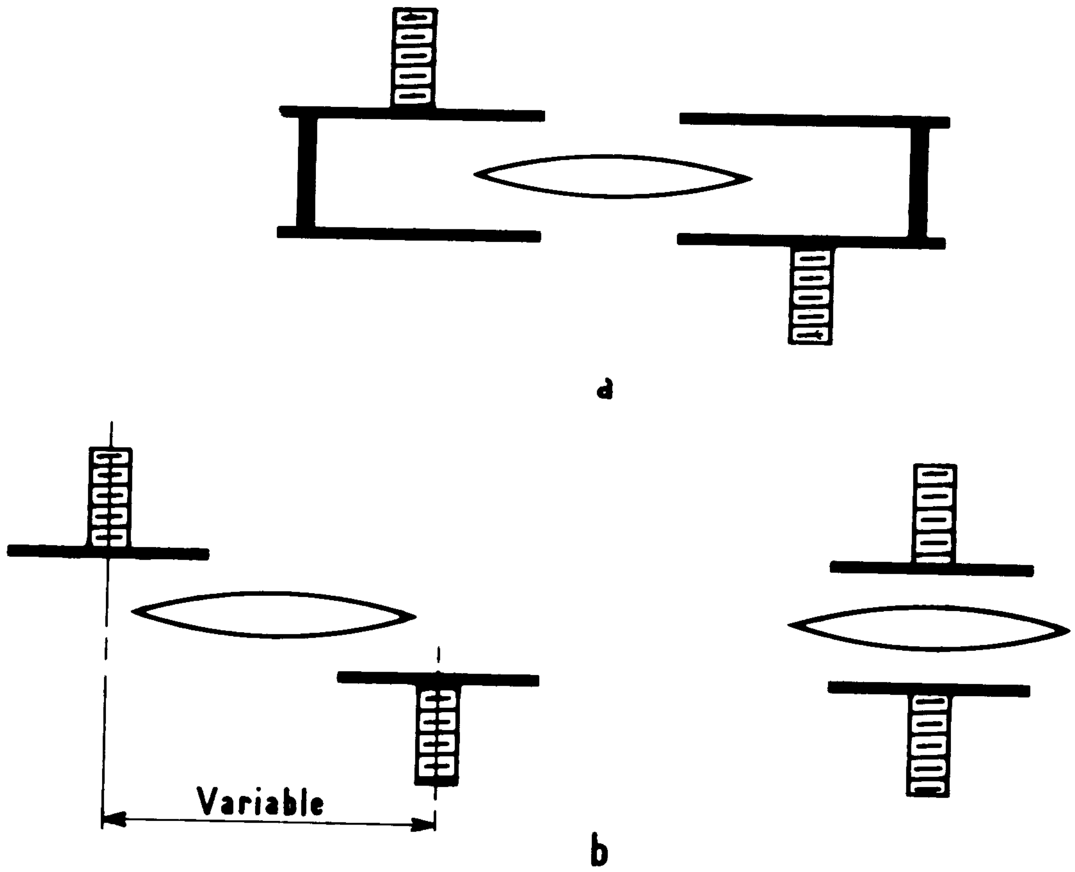
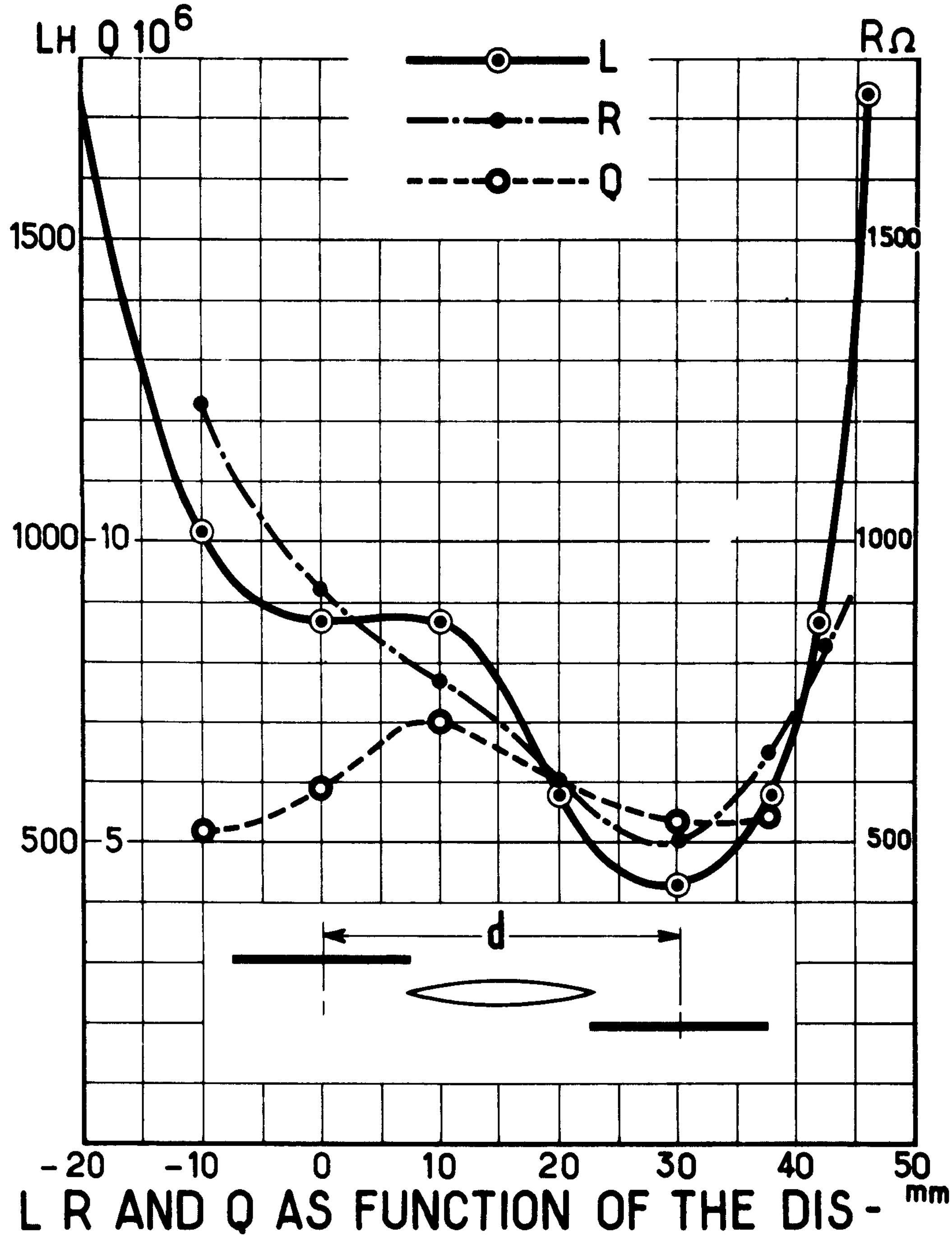


Fig. n° 7

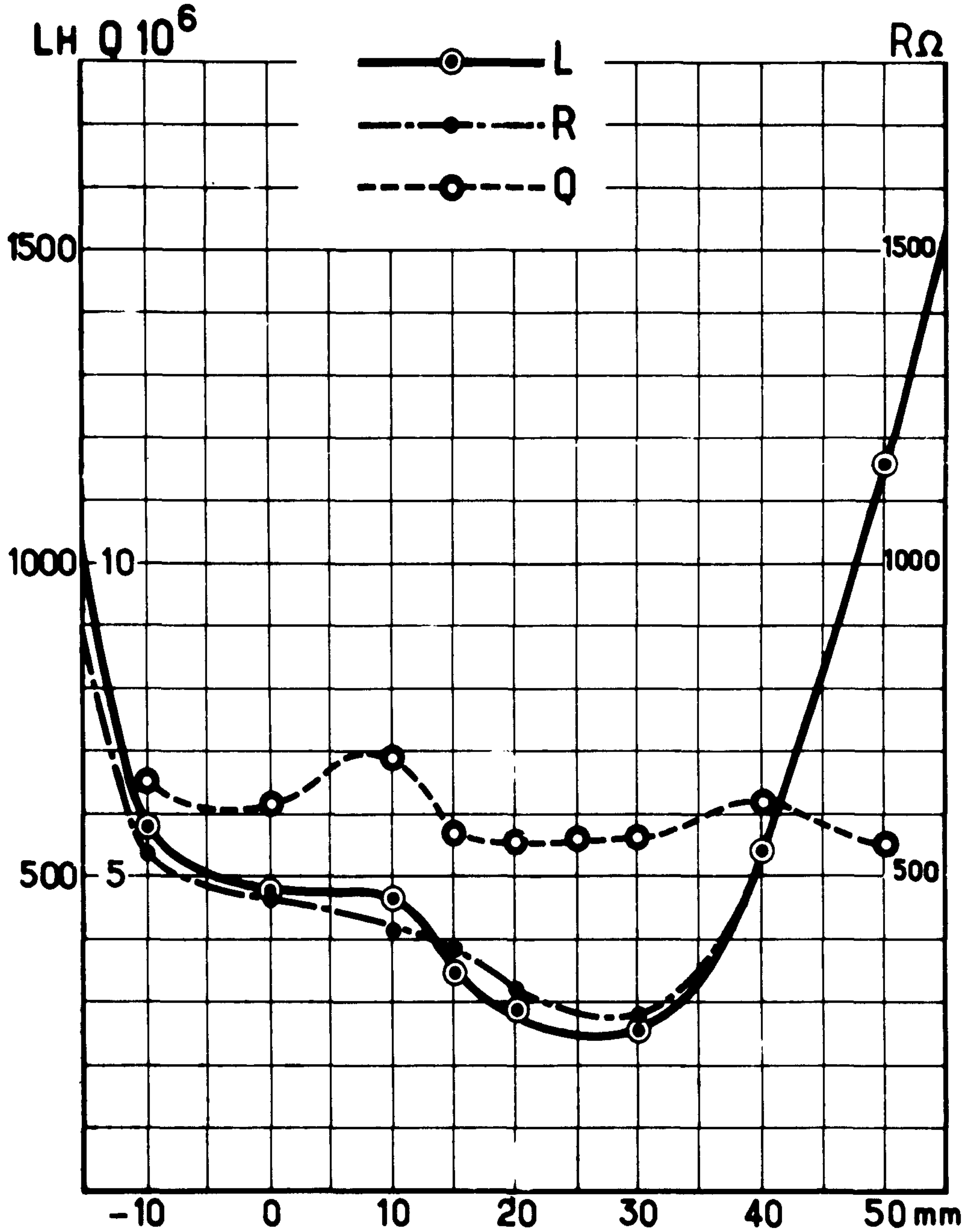


SETS OF ELECTRODES FOR THE EXCITATION OF THE UNPLATED CRYSTALS

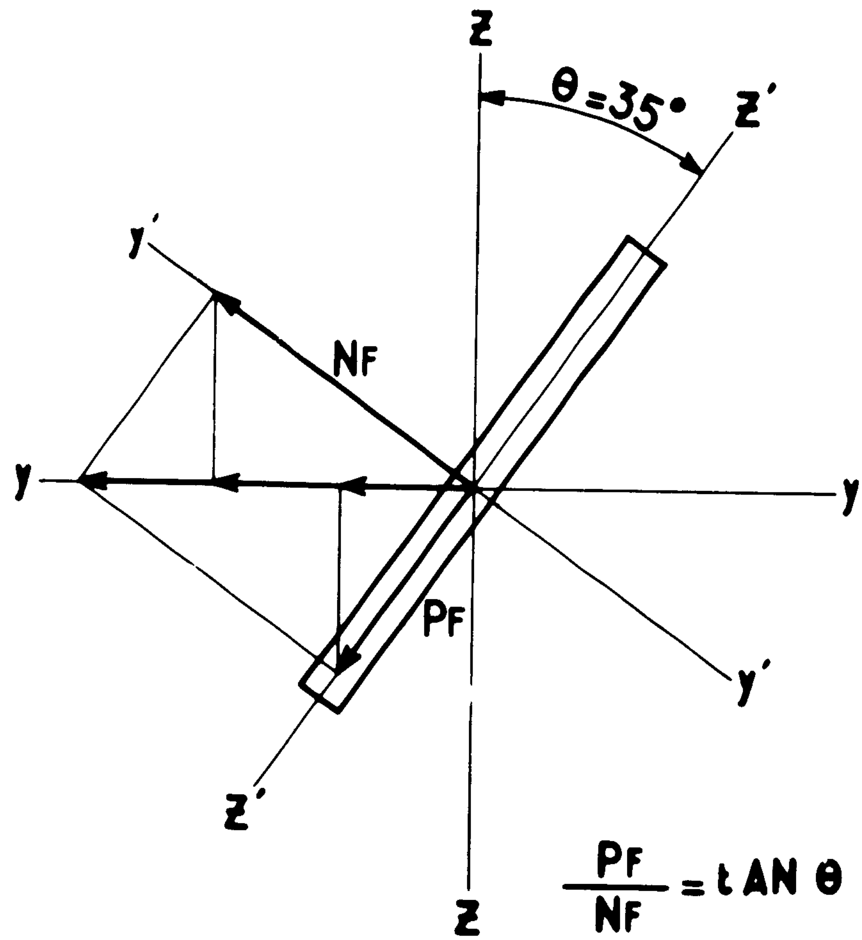
Fig. 8



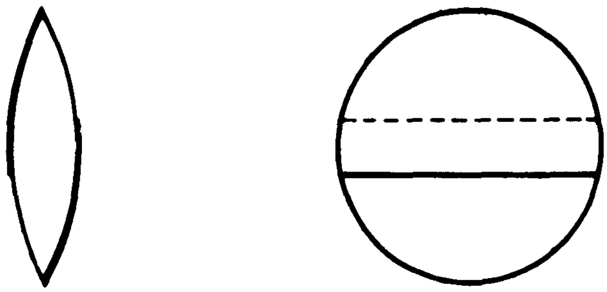
L R AND Q AS FUNCTION OF THE DIS- -TANCE d. GAP 10mm. Fig. 9



L R AND Q AS FUNCTION OF THE DIS-
-TANCE d. GAP 8 mm. Fig. 10



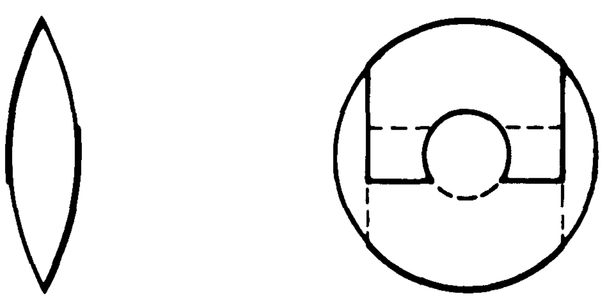
FIELD DIAGRAM
Fig. 11



COMPOSED FIELD PLATING PATTERN. Fig. 12

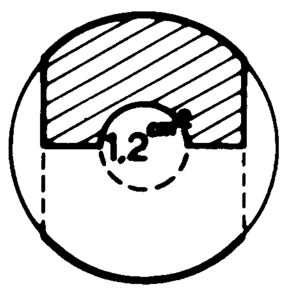
GAP	OVERLAP	L	Rv	Q
1,0	0	29,6	33	5,6
0,8	0,4	20,6	22,2	5,8
0,8	0,5	17,7	17,8	6,2

DATA OF IMc CRYSTAL COMPOSED FIELD,
OVERLAP ALONG X AXIS. Fig. 13



COMPOSED FIELD PLATING PATTERN. Fig. 14

	C_1 10^{-4} pF	L H	R_A Ω	R_V Ω	R_A/R_V	C_0 pF	Q 10^6
CRYSTAL # 237	5,11	49,5	500	37	13,5	6,5	8,4
CRYSTAL # 240	5,05	50,1	484	42	11,5	6,5	7,5



DATA FOR IMc CRYSTAL WITH
COMPOSED FIELD EXCITATION

Fig. 15

Appendix I

Aging of N°242 crystal excited by composed field after 45 days of oscillation in 10^{-10}
242/Atomichron

		4 am	4 pm			4 am	4 pm			4 am	4 pm			4 am	4 pm
Feb.	4	-17.6	-16.7	Mar.	1	+ 7.4	+ 8.5	Apr.	1	+46.7	+48.5	May	1	+80.7	+81.8
	5	16.5	17.1		2	9.2	9.1		2	-	49.2		2	82.1	83.4
	6	17.1	17.7		3	10.0	10.9		3	-	49.3		3	84.0	83.8
	7	15.1	15.3		4	11.2	12.0		4	51.1	51.8		4	85.0	85.6
	8	16.6	16.0		5	11.9	13.1		5	51.6	52.3		5	85.7	86.0
	9	15.3	15.4		6	13.1	14.0		6	53.0	53.8		6	-	87.2
	10	14.5	14.2		7	15.3	14.2		7	55.0	55.4		7	87.7	88.2
	11	13.5	12.6		8	15.6	14.8		8	55.4	56.4		8	88.8	89.6
	12	12.3	13.4		9	-	-		9	56.2	56.9		9	92.1	92.1
	13	10.6	11.6		10	-	-		10	58.0	58.1		10	93.0	94.8
	14	9.2	8.2		11	-	21.6		11	-	58.8		11	95.4	95.7
	15	6.5	7.7		12	22.1	23.2		12	59.5	60.7		12	96.6	97.3
	16	6.3	-		13	24.1	24.6		13	61.4	62.1		13	[illegible]	97.9
	17	-	-		14	23.5	24.8		14	62.5	62.9		14	98.7	98.6
	18	-	5.1		15	26.4	26.3		15	63.7	64.4		15	99.1	100.1
	19	3.8	2.4		16	26.6	28.8		16	64.2	64.6				
	20	3.1	2.6		17	26.4	29.8		17	66.2	66.5				
	21	2.2	1.1		18	31.6	31.9		18	67.7	67.1				
	22	0.6	+ 0.9		19	32.5	33.3		19	67.5	68.2				
	23	+ 2.2	2.1		20	-	35.0		20	70.2	70.6				
	24	2.3	2.5		21	36.6	34.8		21	70.7	71.4				
	25	-	3.1		22	35.9	37.8		22	71.4	72.4				
	26	3.7	5.6		23	37.5	39.1		23	73.3	72.9				
	27	6.6	5.7		24	40.0	39.8		24	73.8	74.1				
	28	7.5	6.9		25	39.1	41.9		25	-	75.2				
					26	40.1	43.8		26	76.6	76.6				
					27	43.1	44.6		27	77.3	-				
					28	44.3	43.7		28	-	-				
					29	44.8	48.7		29	-	80.8				
					30	46.0	46.8		30	79.4	81.1				
					31	46.2	47.0								

Appendix II

Preliminary aging of N°96 crystal excited by parallel field, gap 0.8mm

N°96/Atomichron in 10^{-10}

		4 am	4pm
March	16	569.2	601.5
	17	633.7	659.8
	18	684.7	712.3
	19	734.8	751.1
	20	-	-
	21	809.1	822.7
	22	839.4	851.3
	23	866.4	877.3
	24	890.1	900.9
	25	913.9	920.7
	26	933.3	940.9
	27	953.[illegible]	959.3
	28	970.6	976.3
	29	986.6	992.9
	30	1001.1	1006.9
	31	1015.2	1023.9
April	1	1030.9	1027.5